UQ&M SIG in High Value Manufacturing SIG

Plenary Overview

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KTN
the Knowledge Transfer Network

ktn-uk.org @KTNUK

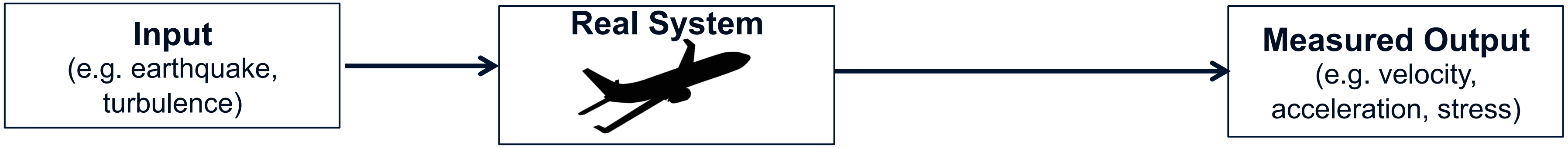
Context... Why Uncertainty Quantification?

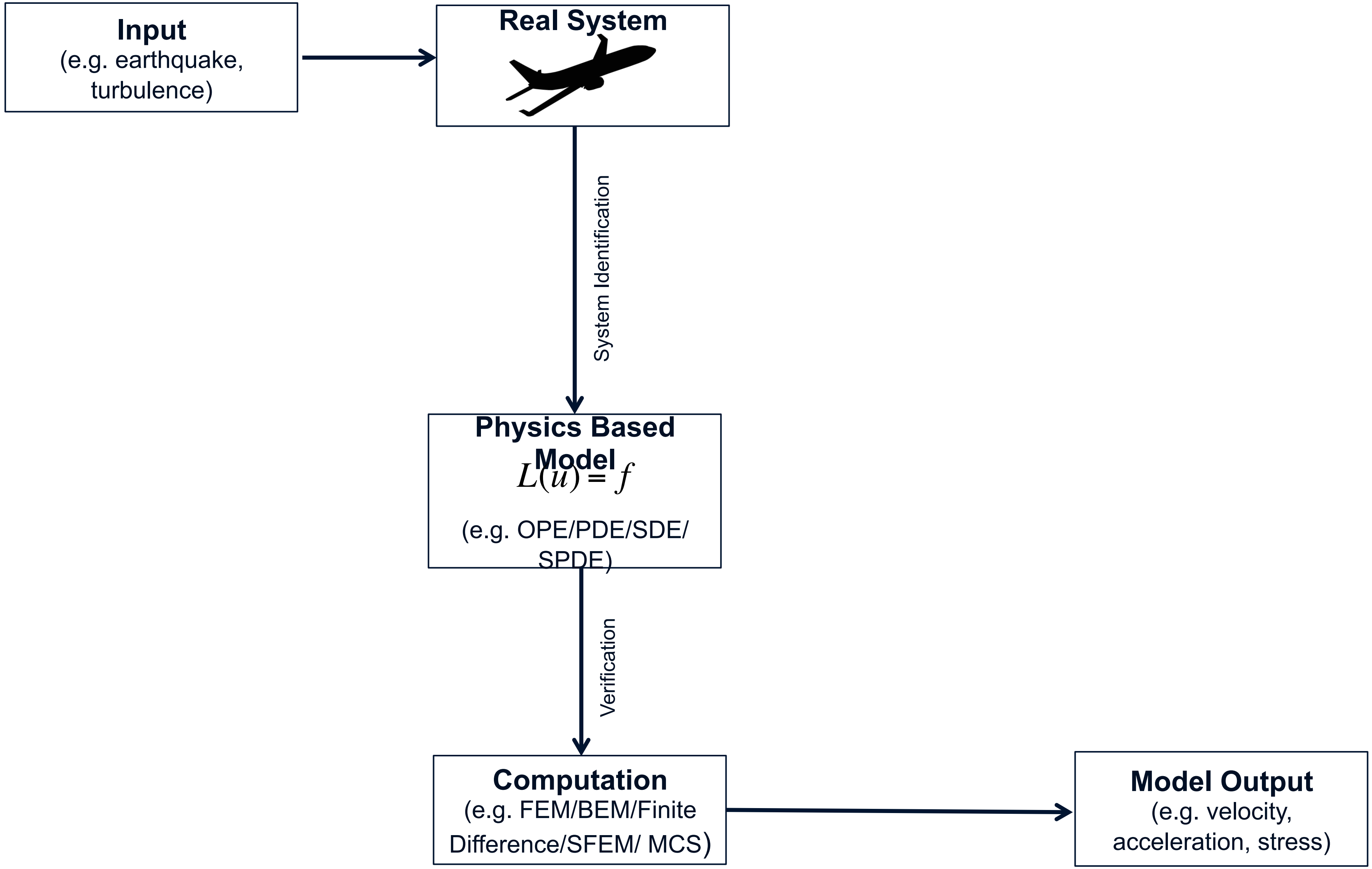
- Whether bringing a new product from conception into production or operating complex plant and production processes, success rests on careful management and control of risk in the face of many interacting uncertainties.

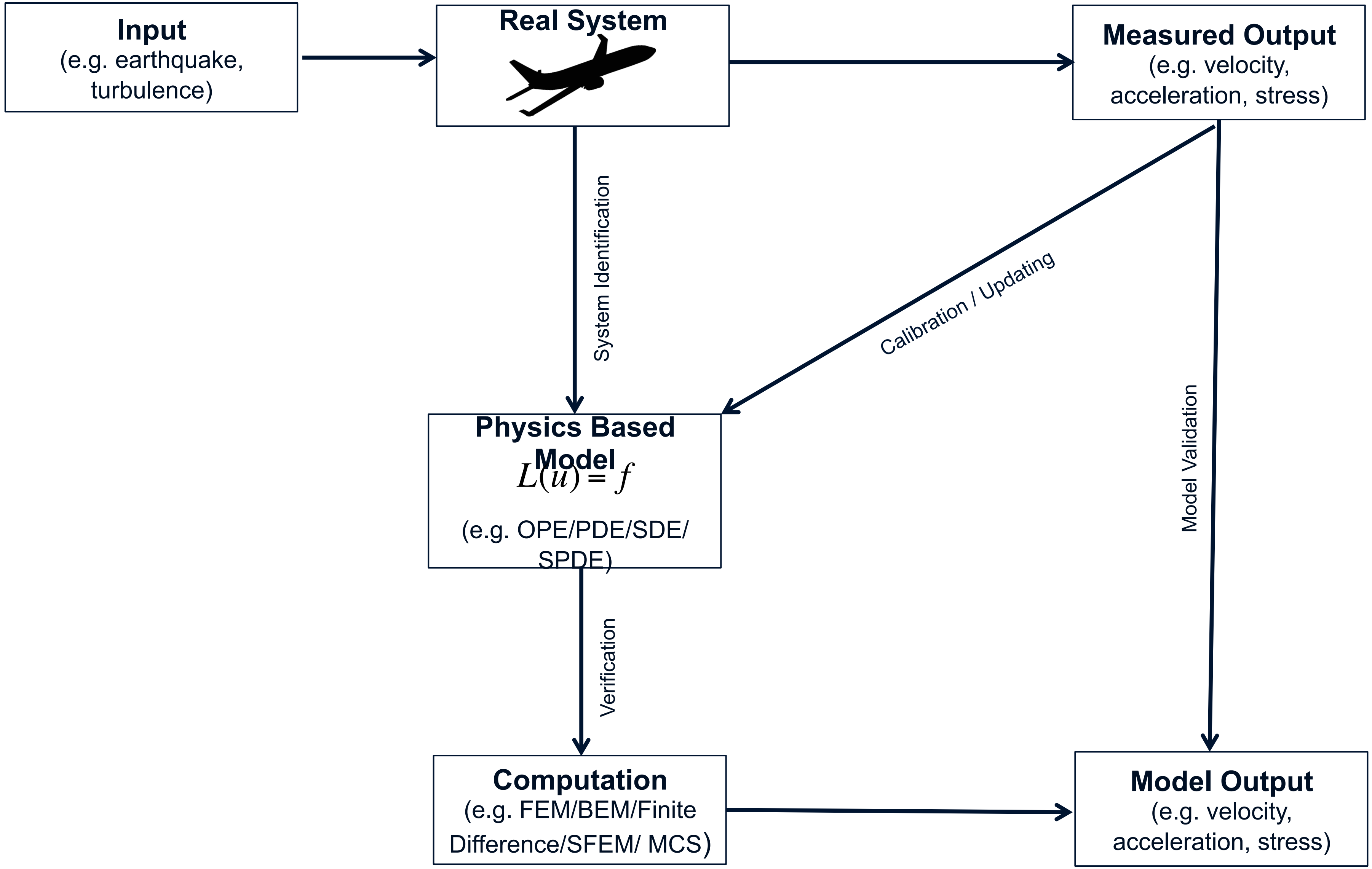
- Today's fiercely competitive market and increasingly stringent regulatory environment is such that there is very little margin for error.

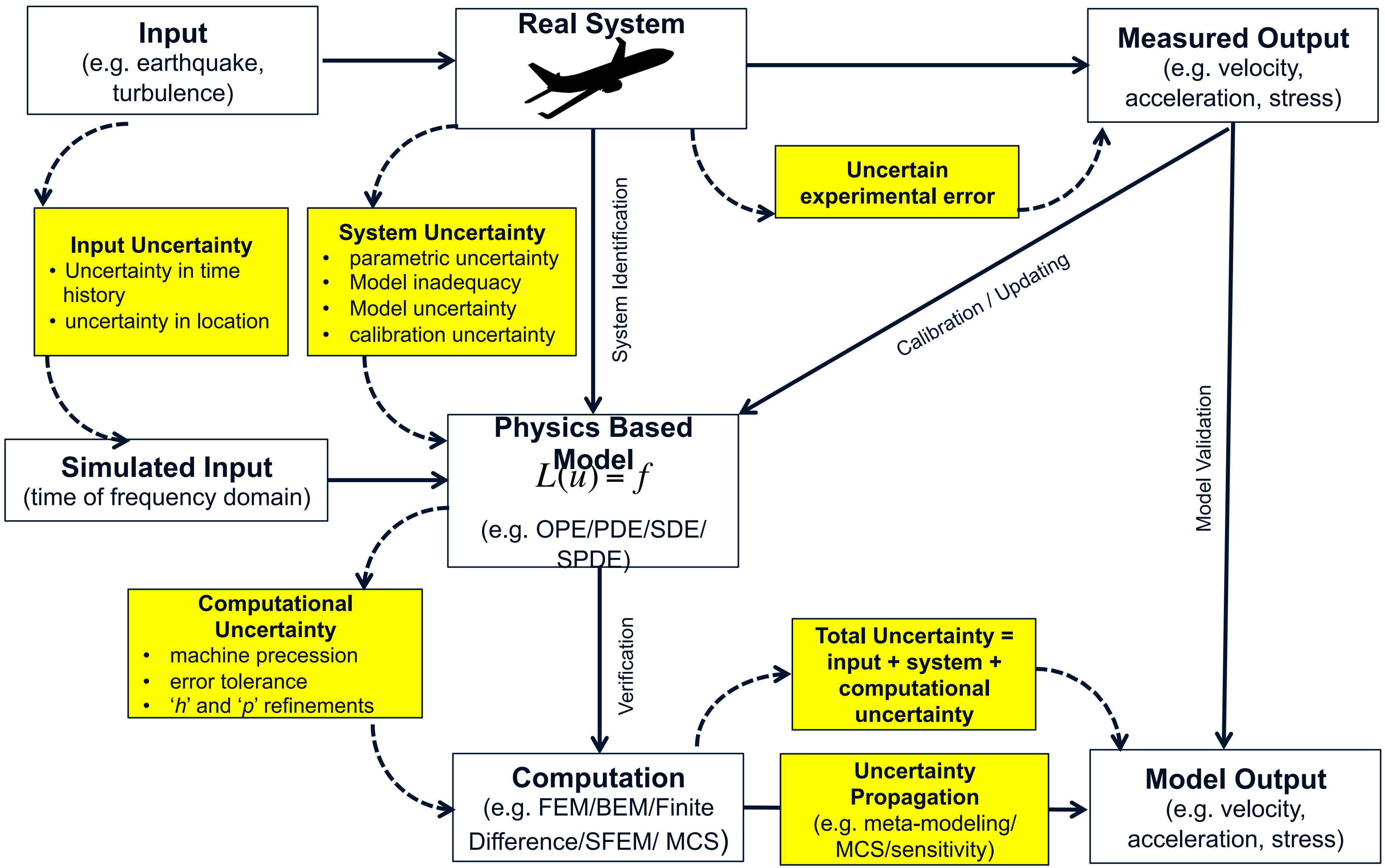
- Failure to understand and manage risks can result in severe financial penalties and even damage to reputation.

- When computational simulations are used, these various risks and uncertainties must be accounted for.


Input
(e.g. earthquake, turbulence)
Real System
Measured Output
(e.g. velocity, acceleration, stress)


Input
(e.g. earthquake, turbulence)
Real System
System Identification
Physics Based Model
$L(u) = f$
(e.g. OPE/PDE/SDE/ SPDE)
Verification
Computation
(e.g. FEM/BEM/Finite Difference/SFEM/ MCS)
Model Output
(e.g. velocity, acceleration, stress)


Input
(e.g. earthquake, turbulence)
Real System
Measured Output
(e.g. velocity, acceleration, stress)
System Identification
Calibration / Updating
Model Validation
Physics Based Model
$L(u) = f$
(e.g. OPE/PDE/SDE/ SPDE)
Verification
Computation
(e.g. FEM/BEM/Finite Difference/SFEM/ MCS)
Model Output
(e.g. velocity, acceleration, stress)


Input
(e.g. earthquake, turbulence)
Real System
Measured Output
(e.g. velocity, acceleration, stress)
Uncertain experimental error
Input Uncertainty
• Uncertainty in time history
• uncertainty in location
System Uncertainty
• parametric uncertainty
• Model inadequacy
• Model uncertainty
• calibration uncertainty
System Identification
Calibration / Updating
Model Validation
Simulated Input
(time of frequency domain)
Physics Based Model
L(u) = f
(e.g. OPE/PDE/SDE/ SPDE)
Computational Uncertainty
• machine precession
• error tolerance
• 'h' and 'p' refinements
Verification
Total Uncertainty = input + system + computational uncertainty
Computation
(e.g. FEM/BEM/Finite Difference/SFEM/ MCS)
Uncertainty Propagation
(e.g. meta-modeling/ MCS/sensitivity)
Model Output
(e.g. velocity, acceleration, stress)

Topics…

1. What are the latest research developments with the potential to have impact on the design and simulation user communities?

2. How can these developments be further enhanced for exploitation by designers?

3. What are the opportunities and barriers to uptake of these new design and simulation tools?

4. What are the potential risks and benefits of uptake of these new design and simulation tools?

Latest Research…

A. Uncertainty Modeling

- Random variable
- Random process
- Random fields
- Rare events – Poisson's process, Gumbelll distribution
- Maximum entropy principle
- Random matrices
- Bayesian inference
- Bounded uncertainties – convex models
- Multi-scale stochastic mechanics of materials and components
- Non-probabilistic interval and fuzzy-based methods

B. Calibration and Inverse Problems

C. Uncertainty Propagation

Latest Research…

A. Uncertainty Modeling

B. Calibration and Inverse Problems

- Stochastic model updating
- System identification
- Kalman filters
- Ensemble and particle Kalman filters
- Bayesian updating
- Modal assurance criterion

C. Uncertainty Propagation

Latest Research…

A. Uncertainty Modeling

B. Calibration and Inverse Problems

C. Uncertainty Propagation

Sampling Methods
- Monte Carlo methods
- MCMC
- 2k factorial design
- Sobol sequence
- CCD
- Latin hypercube
- D-Optimal design
- Box-Behnken
- A-Optimal design
- I-Optimal design
- Taguchi OA

HPC and Algorithm Design
- Parallel MCMC
- Cloud computing
- HPC
- Fast propagation methods
- Probabilistic numerics

Meta-modeling
- Gaussian process emulation
- Non-intrusive polynomial chaos
- PR
- HDMR
- PCE
- ANN
- Kriging
- MARS
- RBF
- MLS
- GMDH-PNN
- SVM

Optimisation
- Probabilistic optimisation
- Design optimisation under uncertainty

Reliability
- First and second order reliability analysis (FORM / SORM)
- Subset simulation
- Line sampling
- Asymptotic methods
- Design for reliability

Stochastic DE's
- Inference in DE models
- Stochastic FEM
- Numerical integration of stochastic ODE's and PDE's
- Spectral methods
- Reduced order methods
- Random vibration
- Ito calculus

How to exploit?...

- The top level aim of the SIG is to draw together an UQ&M community and provide a structured meeting space where all the players can share their aspirations, knowledge and expertise

- It is to be expected that much of tangible value will be created, such as:
    - Collaborative groupings that identify real benefit in working together
    - The development and refinement of challenges and aspirations
    - The emergence of a clutch of industry pulled projects that make significant advances against the above challenges within given industrial HVM sectors
    - An increasingly statistics-savvy engineering design and assessment community
    - A highly visible joined up and holistic UK based UQ&M capability that can respond positively to end-user aspirations and requirements

Opportunities and barriers [1]

Opportunities…

- Historically, chief engineers and project managers have estimated and managed risk using mostly human judgment founded upon years of experience and heritage.

- In the modern era of HVM, the design and engineering of products rely increasingly on computer modelling – "*The Era of Virtual Design and Engineering*"

- This era opens the opportunity to deal with uncertainty in a systematic formal way.

  - Better management of risk attaching to key decisions
  - Convergence on designs which are robust in the face of uncertainty

Opportunities and barriers [2]

Barriers…

- The challenges to be met in progressing to full industrial maturity are substantial

- Modelling of Data
    - Much is epistemic. It is due to lack of knowledge and must be modelled by expert judgment
    - Identifying and modelling dependency and covariance of such data

- Functional dependency. (co-variance of uncertainty in parameters shared and operated upon by coupled tools/models)

- Cross-discipline propagation of uncertainty

Opportunities and barriers [3]

Barriers…

- Handling a large number of analyses across a high dimensional parameter space
- Developing early stage designs with a high level of confidence in downstream mitigation strategies for achieving compliance with performance requirements
- Inverse (i.e. which uncertain inputs contribute most to uncertain output) across coupled/ feedback loop processes
- Cultural/Educational. Engineers will need to be trained to an appropriate level in statistics

Risks and benefits to industrial adoption

- Gathering of credible input data. Inconsistent approaches to elicit uncertainties.
  - Poor treatment of input uncertainty can lead to false confidence of a UQ analysis

- Time and resources are needed to train engineers in an appropriate level of statistics
  - Lack of general purpose software codes

- Significant increase in computational cost, need strong value judgment to justify.

- Conveying information arising from UQ to decision makers effectively.

Thanks

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